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Synthesis of an Assigned Structure Generator of Binary Sequence Sets

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Abstract

For the compact testing of separate units of complex digital systems, the problem of synthesis of the generator structure that reproduces an assigned sequence of binary sets is being solved. Increased attention is given to issues of the non-excessive reproduction of sets sequence and structural organization simplicity. The solution is based on the application of a mathematical tool for linear sequence machines. The software implementation of this mathematical tool is offered. Additionally, means of the binary sets generation process visualization are presented.

Keywords: diagnostics object, self-testing, check test, linear sequence machine, binary sets generator

INTRODUCTION

The self-testing of diagnostics objects (DO) is the most maximally autonomous way of in-built test diagnostics, because the test impacts generation and the results of test information passage analysis is done without the support of system tools. Actually, any self-testing method is based on test impacts generation and the compact presentation of test impact passage results using a signature analyzer. That's why the task of a rational choice of built-in equipment parameters is important for any technology of DO manufacturing [1].

Currently, the need for economical testing systems is increasing with the rise in the integration level of the computer equipment component base. In relation to this, there is a trend of reducing the complexity of diagnostics tools hardware. Built-in testing tools have an important application, in particular, in the development of large and super-large integrated circuits [2].

A control test, especially when dealing with limited time dedicated to the control, is a "mixture" of pseudo-random and deterministic sets of test impacts. Hardware for the generation of pseudo-random sets is well known, and there are no serious problems in their implementation [3, 4]. However, the storage of the deterministic part of a check test in read-only memory, as a rule, is not always acceptable, because it is related to significant hardware requirements. In conjunction with this, the task of creating simple hardware that reproduces assigned binary sets sequence that compose the deterministic part of the check test arises.

The theoretical justification for choosing hardware generators with assigned properties is most convenient to do from the position of the mathematical tool of linear sequence machines (LSM) [5].

AN AUTONOMOUS LINEAR SEQUENCE MACHINE AS A BINARY SETS SEQUENCE GENERATOR

In [6], it was proposed to use LSM which under the impact of a special control sequence generates an assigned binary sets sequence. In this process, excessive intermediate sets appear at the output of LSM that have to be masked. In [7] a register of shift with non-linear feedback function is composed. However, even in this case it is not possible to get rid of excessive intermediate sets.

An autonomous linear sequence machine (ALSM), whose state does not depend on input impacts, is traditionally used for the creation of pseudo-random binary sets sequence. In this work, the following task is set up: to use ALSM as a simple generator that will be able to reproduce an absolutely precisely assigned binary sets sequence forming check test.

Processes in ALSM with m-outputs and n-memory elements (Figure 1) are described by the linear system of state equations and a linear system of equations of outputs that in matrix form look as follows:

$$S^{t+1} = AS^t,$$
$$Y^t = CS^t,$$

where $A = \|a_{ij}\|_{n\times n}, C = \|c_{ij}\|_{m\times n}$ are characteristic matrices in which elements in behavior equations are presented in a Galois field GF(2). The output Y^t and state of S^t ALSM in the time t are given as corresponding vector-columns $Y^t = \|y_i^t\|_m, S^t = \|s_i^t\|_n$.

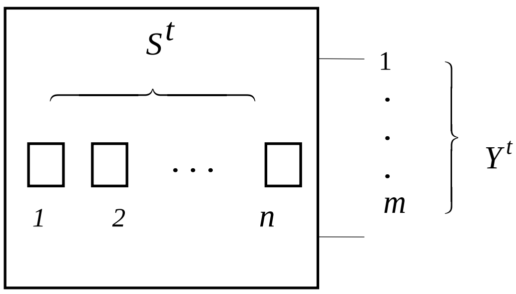

Figure 1. The structure of an autonomous linear sequence machine (ALSM)

The ALSM structure is described by memory elements A connections matrix, each element a_{ij} of which is determined in the following way:

$$a_{ij} = \begin{cases} 1, & \text{if the output of the } j\text{-th memory element is connected to the input of the } i\text{-th memory element;} \\ 0, & \text{otherwise.} \end{cases}$$

In a similar way, a matrix C that establishes a connection between memory elements and outputs may be integrated.

THE SYNTHESIS OF A BINARY SETS SEQUENCE GENERATOR

The considered method of the synthesis of a binary sets assigned sequence generator

$$H_n = |Y(0) \quad Y(1) \quad \dots \quad Y(n-1)|$$

consists of the following. It is necessary to find such a polynomial

$$\xi(x) = x^r + g_{r-1}x^{r-1} + \dots + g_0$$

of a minimal degree $r \le n$, that columns H_n, starting with $Y(r)$, could be presented by the same linear combination of previous r columns. Analytically, it could be presented in the following way:

$$Y(j) = g_{r-1}Y(j-1) + g_{r-2}Y(j-2) + \dots$$
$$\dots + g_0 Y(j-r), \; j = \overline{r,n}.$$

The characteristic matrices of the sequence generator H_n that shift register with feedback $g_{r-1}, g_{r-2}, \dots, g_0$ and original state $S^0 = |1 \quad 0 \quad \dots \quad 0|^T$, will look like:

$$A = \begin{vmatrix} g_{r-1} & g_{r-2} & \cdots & g_0 \\ 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 10 \end{vmatrix},$$

$$C = H_r F_r^{-1} = H_r \begin{vmatrix} a_1^0 & a_1^1 & \dots\dots & a_1^{r-1} \\ 0 & a_1^0 & \dots & a_1^{r-2} \\ 0 & 0 & \dots & a_1^{r-3} \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & a_1^0 \end{vmatrix}^{-1},$$

where $a_1^i = \sum_{j=1}^{i} a_1^{i-j} g_{r-j}, \quad a_1^0 = 1, \quad g_{r-j} = 0$ at $r - j < 0$. The consequence is that determined in the following way:

$$H_r = |Y(0) \quad Y(1) \quad \dots \quad Y(r-1)| =$$
$$= C \cdot |A^0 \cdot S^0 \quad A^1 \cdot S^0 \quad \dots \quad A^{r-1} \cdot S^0| = C \cdot F_r$$

In a number of cases the inverse matrix F_r^{-1} could be calculated in a more simple way:

$$F_r^{-1} = \begin{vmatrix} d_1^0 & d_1^1 & \dots\dots & d_1^{r-1} \\ 0 & d_1^0 & \dots & d_1^{r-2} \\ 0 & 0 & \dots & d_1^{r-3} \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & d_1^0 \end{vmatrix},$$

where $d_1^i = \sum_{k=0}^{i-1} d_1^k a_1^{i-k}, \quad d_1^0 = 1, i = \overline{1, r-1}.$

In a worst case scenario, when it is not possible to find the linear combination mentioned above, a polynomial $\xi(x)$ will look like $\xi(x) = x^n$, and the generator of an assigned sequence will be n-bit shift register without feedback connections.

Example. The complete text of integrated circuit (IC) **TI SN74153N** consists of the following sets [8]:

$$H_8 = \begin{matrix} & Y(0) & Y(1) & Y(2) & Y(3) & Y(4) & Y(5) & Y(6) & Y(7) & \\ a & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & \rho_1 \\ b & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & \rho_2 \\ c & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & \rho_3 \\ d & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & \rho_4 \\ e & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & \rho_5 \\ f & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & \rho_6 \end{matrix}.$$

It is needed to make ALSM that reproduces assigned binary sets sequence.

Let us transform the matrix H_8 by lines to canonical form H_{can} [9]:

$$\begin{array}{cc} & \begin{array}{cccccccc} 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \end{array} \\ H_{can} = & \left|\begin{array}{cccccccc} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{array}\right| \begin{array}{c} \rho_1+\rho_3+\rho_4 \\ \rho_3+\rho_6 \\ \rho_2+\rho_3+\rho_4+\rho_6 \\ \rho_1+\rho_6 \\ \rho_2+\rho_3+\rho_4 \end{array} . \end{array}$$

H_{can} must meet the requirements:

- not to contain zero lines (linear dependant lines are transformed in zero ones);

- the first one in each line must be located on the right from the first one of the previous line;

- in each column containing such a unit, the remaining elements are equal to zero, if they are located below this one.

In this case, H_{can} has the appearance typical for this particular case, because the first five columns of the matrix H_{can} are linear independent.

In matrix H_{can} in the lower line the first one is in column number four. Consequently, the lower limit of the digit capacity of ALSM in search is equal to five.

The column number five is presented in the form of a linear combination of the five previous ones

$$Y(5) = Y(3) + Y(2) + Y(0).$$

However

$$Y(6) \neq Y(4) + Y(3) + Y(1).$$

Consequently, we construct the linear combination dependence of the column number six from the six previous ones $Y(6) = Y(3) + Y(2) + Y(1)$, because the fifth column is no longer expressed through the previous columns. This relation stays in power also for column number seven $Y(7) = Y(4) + Y(3) + Y(2)$.

That's why the polynomial in a search takes the form $\xi(x) = x^6 + x^3 + x^2 + x^1$ $(r = 6)$.

Feedback coefficients of the shift register in accordance with $\xi(x)$ is set as follows:

$$g_5 = 0, g_4 = 0, g_3 = 1, g_2 = 1, g_1 = 1, g_0 = 0 .$$

And finally, we calculate the matrix of relations of the ALSM outputs with delay elements

$$C = H_6 F_6^{-1} = \left|\begin{array}{cccccc} 0 & 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{array}\right| \times$$

$$\times \left|\begin{array}{cccccc} 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right| =$$

$$= \left|\begin{array}{cccccc} 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 \end{array}\right| .$$

Synthesized an autonomous linear sequence machine is presented in Figure 2.

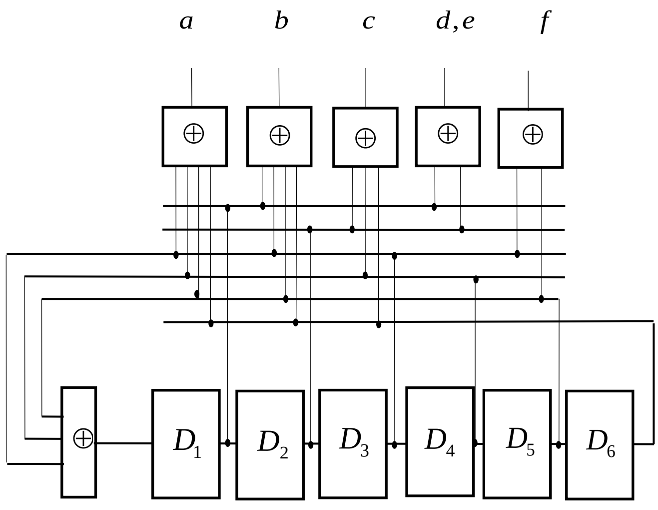

Figure 2. Tests generator for IC **TI SN74153N**

VISUALISATION OF THE GENERATOR FUNCTIONING PROCESS

The software implementation of mathematical models of DO with arbitrary configuration and structure (Figure 3), which was developed by the author in the DELPHI 7.0 programming environment using the hypertext help systems on-line documentation HTML Help Workshop, confirms the validity of the functioning of the developed algorithms.

A step-by-step observation of binary sets generation in the program model allows a visual confirmation of this process.

CONCLUSION

Consequently, the developed algorithm of constructing ALSM reproducing assigned test sets sequence does not require the construction of a special controlling sequence and does not generate the need for excessive sets.

Moreover, the technical implementation of diagnostics process using the proposed tools for compact testing becomes extremely simple. This allows for a significant reduction in the requirements of the qualification of testing specialists and for a significant reduction in total testing cost.

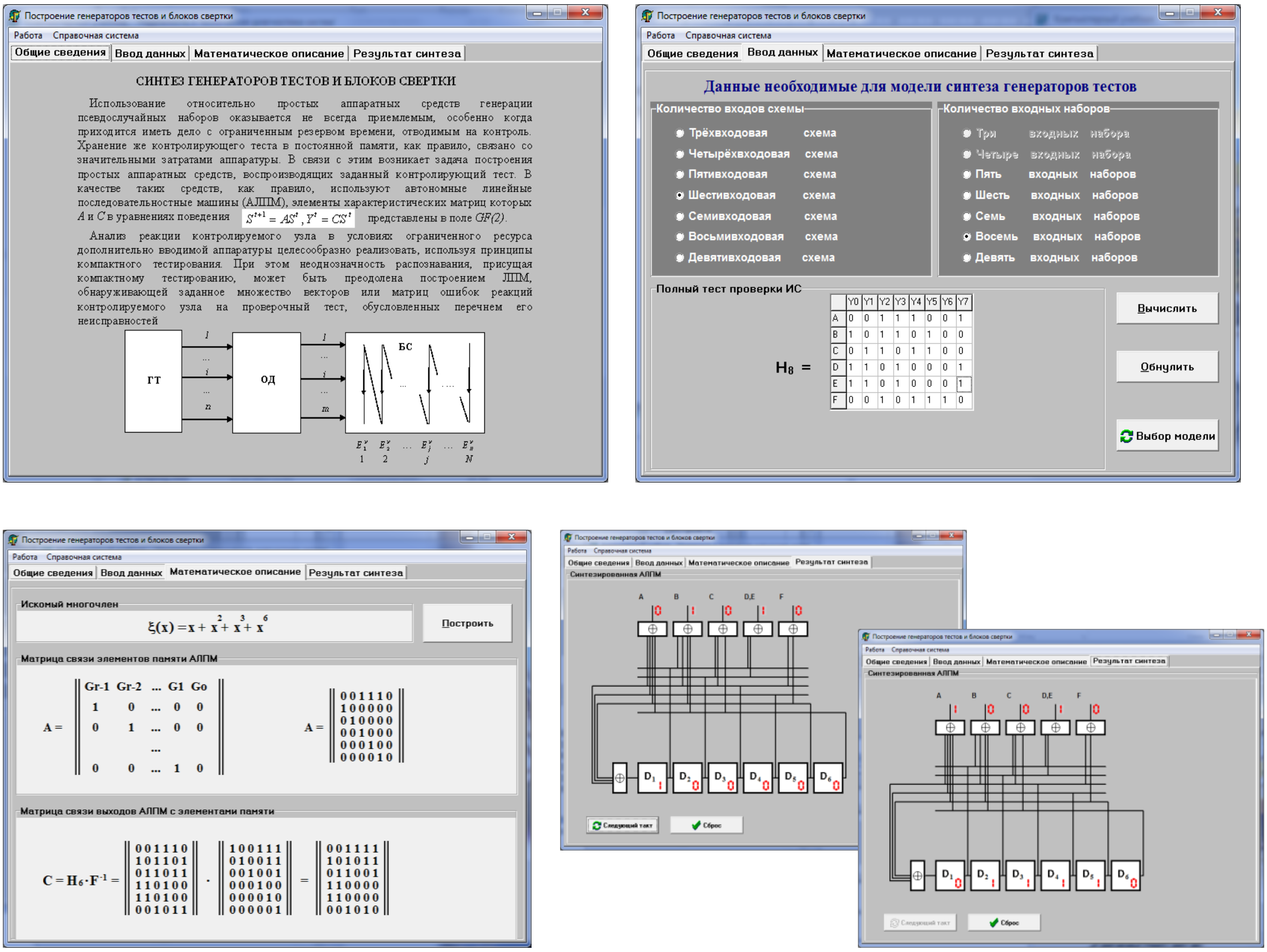

Figure 3. Screen forms of a generator synthesis program model

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